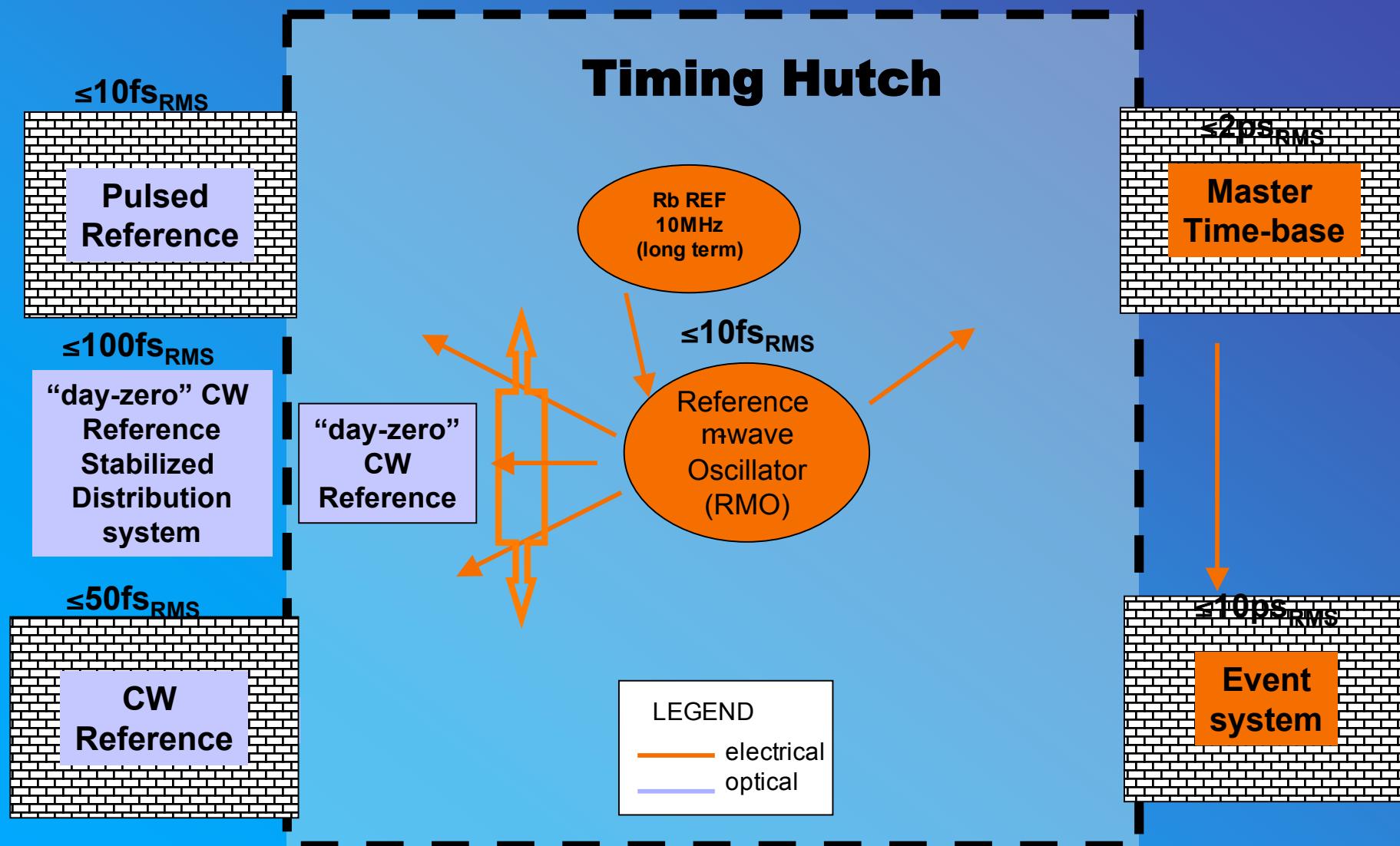


Specifications of the **FERMI@Elettra** optical hybrid timing system

Mario Ferianis
on behalf of the
FERMI Area *Timing*

- The FERMI timing project has been split into the following tasks:
 - Pulsed Clock (phase reference)
 - **2-link test bed implemented at ST (June '08, MIT Contract)**
 - **Pulsed Clock specifications (FESD #022 et al.)**
 - **Purchase Order (PO) issued to MENLOSystems gmbh**
 - **Ref. microwave Oscillator (RMO): to be delivered soon**
 - **Rb 10MHz reference: PO issued**
 - CW Clock (phase reference)
 - LBNL CW
 - **contract signed last september '08**
 - **test bed for 2 CW stabilized links**
 - **Day Zero CW/back-up system**
 - Trigger generation
 - **Event System (by Micro Research Fin.) integrated into FERMI Timing**
 - Distribution system
 - **blown SM fiber bundle solution adopted**
 - **layout defined; PO under preparation**
 - Timing Hutch
 - **layout & racks defined**

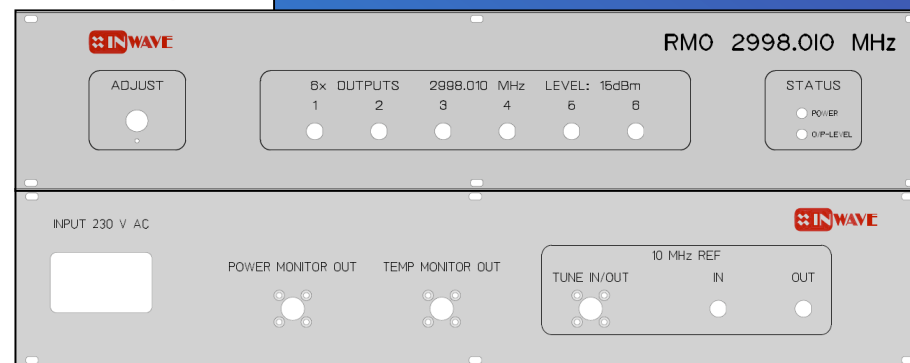
To provide the Phase Reference at $\leq 10\text{fs}$ phase noise level (seed / user laser osc)
To provide the Bunch Clock (50Hz)



The FERMI@Elettra optical hybrid timing system: RMO specifications



parameter	symbol	value	units	notes
Output frequency	f_{RF}	2998.010	MHz	five outputs
Factory set accuracy	f_{RF}	0.1	ppm	manual
Frequency Stability	$\Delta f_{RF \text{ FREE}}$	± 10	ppm	free running, over 8h
Frequency Stability	$\Delta f_{RF \text{ REF}}$	± 1	ppm	with external reference over 8h
Frequency tuning range		± 1	ppm	manual
Frequency Temperature stability		< 0.2	ppm/ $^{\circ}\text{C}$	
Frequency stability between outputs		0.01	ppm	free run. and with ext. ref.
Output power	$P_{RF(i)}$	≥ 15	dBm	$i=1\dots 5$
Output connector			SMA, female	
Phase noise		-80@10Hz -110@100Hz -130@1kHz -140@10kHz -145@100kHz -150@1MHz -160@10MHz	dBc/Hz (respect to the carrier)	
Phase noise (in time units)		$< 20\text{fsRMS}$	[10Hz-10MHz]	
Phase noise (in time units)		$< 10\text{fsRMS}$	[100Hz-10MHz]	
Phase noise between outputs (i, j)		< 10	$\text{fs}_{\text{pk-pk}}$ $i, j=1\dots 5$	
Reference in, Frequency $F_{REF \text{ IN}}$		10	MHz	
Reference in, Level		1	V_{RMS}	
Reference in, connector			SMA, female	
Monitor output connector		DB 15 pin	RS-232 or analogue voltages	
Power Supply		220	VAC	50Hz
Operating environment		24	$^{\circ}\text{C}$	± 1
Size		19", rack-mount		high $\leq 4\text{U}$



ment	Revision: 1.2	Date: 20-Feb-09
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Reference microwave Master Oscillator

Allan variance is defined for a PM (or time deviation) process $x(t)$ with stationary second differences by

$$\sigma_y^2(\tau) = \frac{1}{2\tau^2} \text{var}[x(t) - 2x(t - \tau) + x(t - 2\tau)] \quad (2)$$

Low Noise

• Frequency outputs

Frequency: 1, 5 & 10MHz
 Format: Sinewave
 Amplitude: 1Vrms
 Harmonic: <-40dBc
 Non-harmonic: <-80dBc
 Connector: BNC
 Load impedance: 50Ω
 Location: rear panel

Frequency: 1,5 & 10MHz
 Format: TTL
 Amplitude: >3V Peak
 Pulse width: 50% duty cycle
 Connector: BNC
 Load impedance: 50Ω
 Location: rear panel

SSB phase noise

Offset (Hz)	10MHz
1	-100dBc
10	-130dBc
100	-144dBc
1,000	-150dBc
10,000	-150dBc

Stability

Avg. Time (s) Allan Deviation

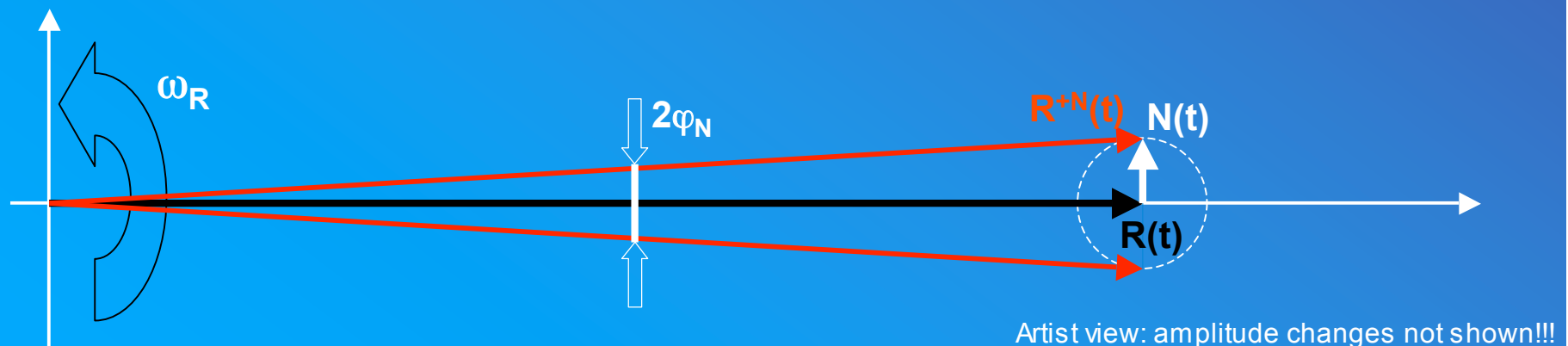
1	<1.5E-11
10	<8E-12
100	<2.5E-12

Aging

Monthly:	<5E-11
Yearly:	<5E-10



- Which is the physical meaning of a phase noise component for a high frequency carrier (i.e the Reference)
- Let's represent the reference signal $R(t)=A_R\sin(2\pi f_R t+\varphi_R)$ by using the vector notation
- It is rotating at $\omega_R=2\pi f_R$; being the Reference we keep it in place
- Let's add to it a phase noise components $N(t)=A_N\sin(2\pi f_N t)$
- For each value of $N(t)$ we obtain the resultant $R+N(t)$ by applying vector sum
- As a consequence, $R(t)$ is oscillating around its nominal angle at f_N and by φ_N
- The value of φ_N depends on the ratio A_N / A_R ; pk-pk jitter of $R(t)$
- The rate at which $R(t)$ moves depends on f_N ; i.e. the offset frequency in the phase noise spectrum



- One good question:
how much does a 100Hz phase noise component affect the Reference signal?
- let's plug in some numbers... $f_R = 3 \text{ GHz}$; $f_N = 100 \text{ Hz}$;
- from phase noise plots, we get relative amplitudes: $A_R / A_N = 80\text{dB} (?)$
- $\varphi_N [\text{rad}] \approx A_N / A_R = 0.0001 \text{ rad}$
- $t_R = 330\text{ps}$; $\varphi_N = 0.0057 \text{ deg} = \mathbf{5.309\text{fs}}$
- but, the *time of flight of FERMI* is...**few ns**
- so the 2nd question is: by how much does the phase of the Reference signal change in few ns?
- $t_N = 10\text{ms}$; considering 2ms around zero crossing
(max slope) ➡ **0.00667fs!!!**
The peak value (5.309fs) is reached after 2.5ms



j	F_N	t	f(t)
[fs]	[Hz]	[sec]	[fs]
5,308686	100	0,000000	0,000000
5,308686	100	0,000002	0,006671
5,308686	100	0,002000	5,048861
5,308686	100	0,002500	5,308686
5,308686	100	0,005000	0,000000
5,308686	100	0,007500	-5,308686
5,308686	100	0,010000	0,000000

MenloSystems
GmbH

Menlo Systems
Am Klopferspitz
D - 82152 Mart
Germany

TECHNICAL PROPOSAL

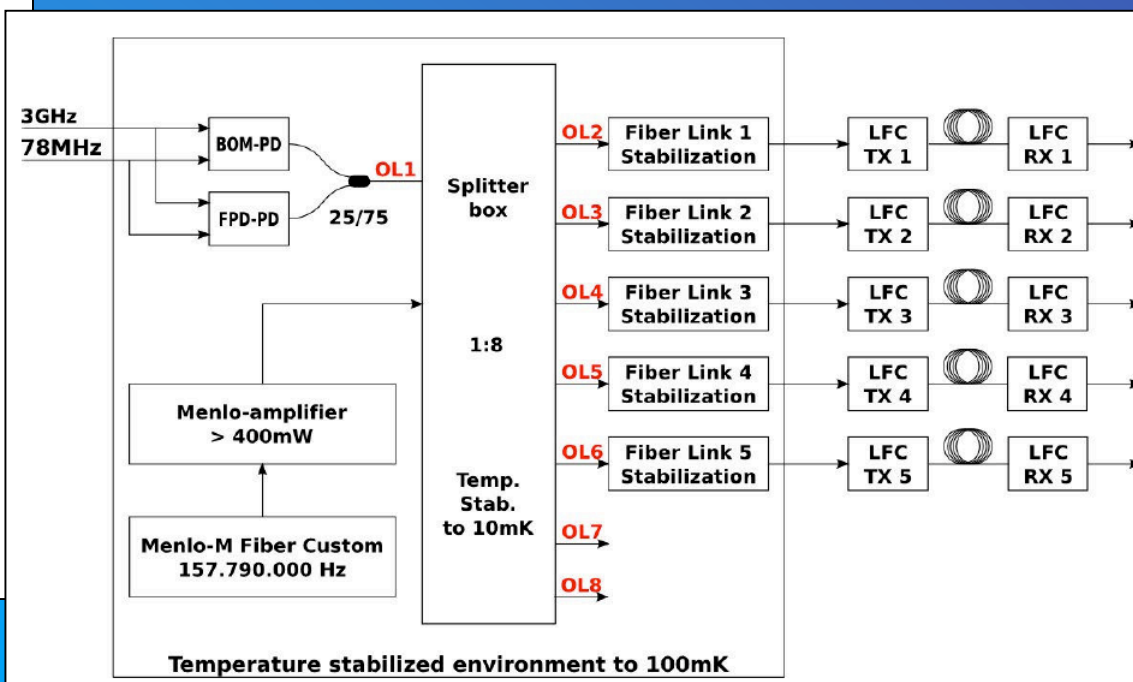
PARAMETER	VALUE	UNITS	NOTES
Fiber laser architecture			Soliton fiber laser
Repetition rate	157.790	MHz	
Repetition rate instability	<160	Hz	measured over 25 h – free running
Tuning range of repetition rate	>800	kHz	available with stepper motor
	>330	Hz	range of piezo transducer
Number of pump diodes	1+1		the second pump diode is the back-up unit to be activated by an external switch or by remote control in case of failure of the first

Pulsed Reference Optical Timing System for the FERMI@elettra Facility

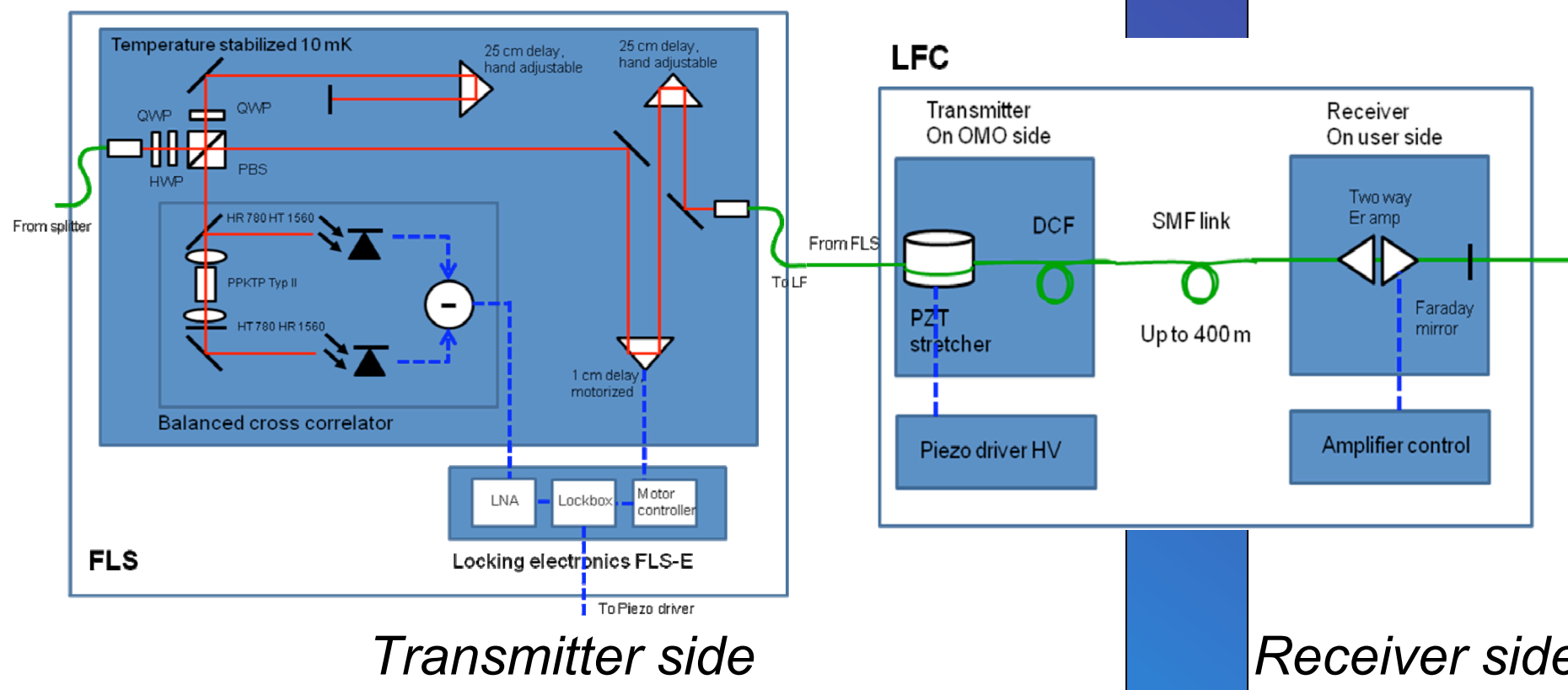
Authors:
Dr. Ronald Holzwarth
Dr. Ida Z. Kozma

Revised:
Dr. M. Ferianis
Dr. F. Rossi

Date:
February 03, 2009



The FERMI@Elettra optical hybrid timing system: Pulsed Reference specifications



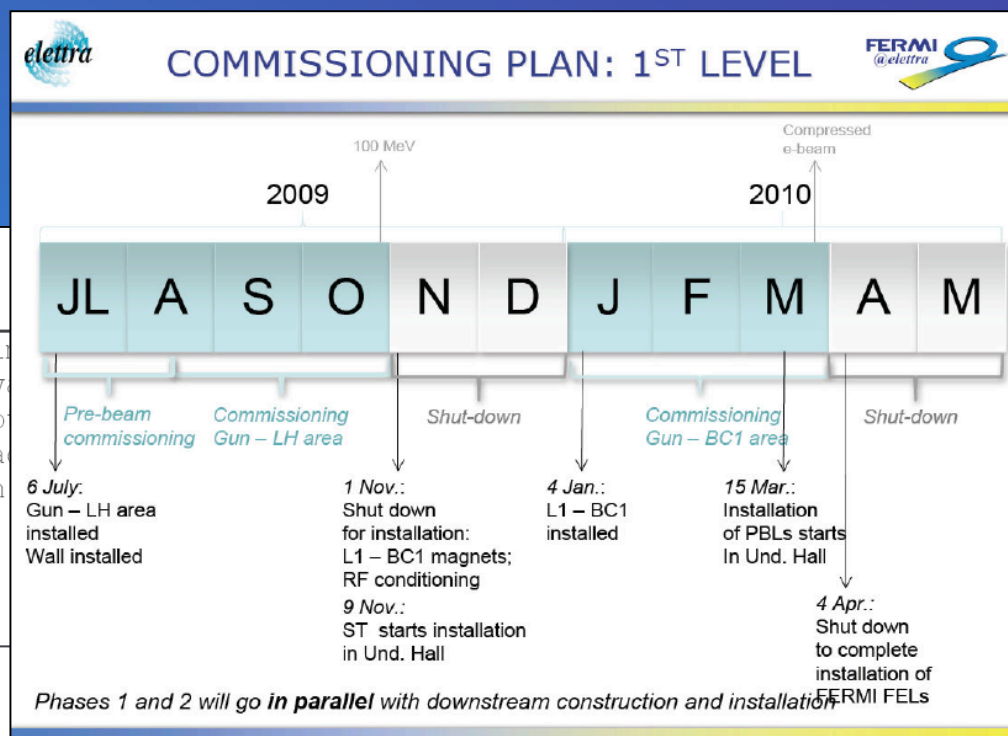
OL #	used for	LFC output type
1	internally split: 3/4 BOM-PD & 1/4 FPD-PD	not available
2	PC Laser oscillator	free air
3	Seed Laser oscillator	free air
4	Electro-Optical Sam- pling station (FEL1)	free air
5	Reference to CW	not available
6	BAM #1	fiber
7	BAM #2	fiber
8	BAM #3	fiber

VERSION1: Optical free space output			
Pulse length	100-200	fs	FWHM; the real value has to be the same for all lines
Average power output	>20	mW	
Optical amplitude stability	0.1	%	RMS, bandwidth[1kHz-10 MHz]
Optical bandwidth	>10	nm	
Wavelength	1560	nm	
Beam diameter	>1	mm	

The FERMI@Elettra optical hybrid timing system: Pulsed Reference specifications

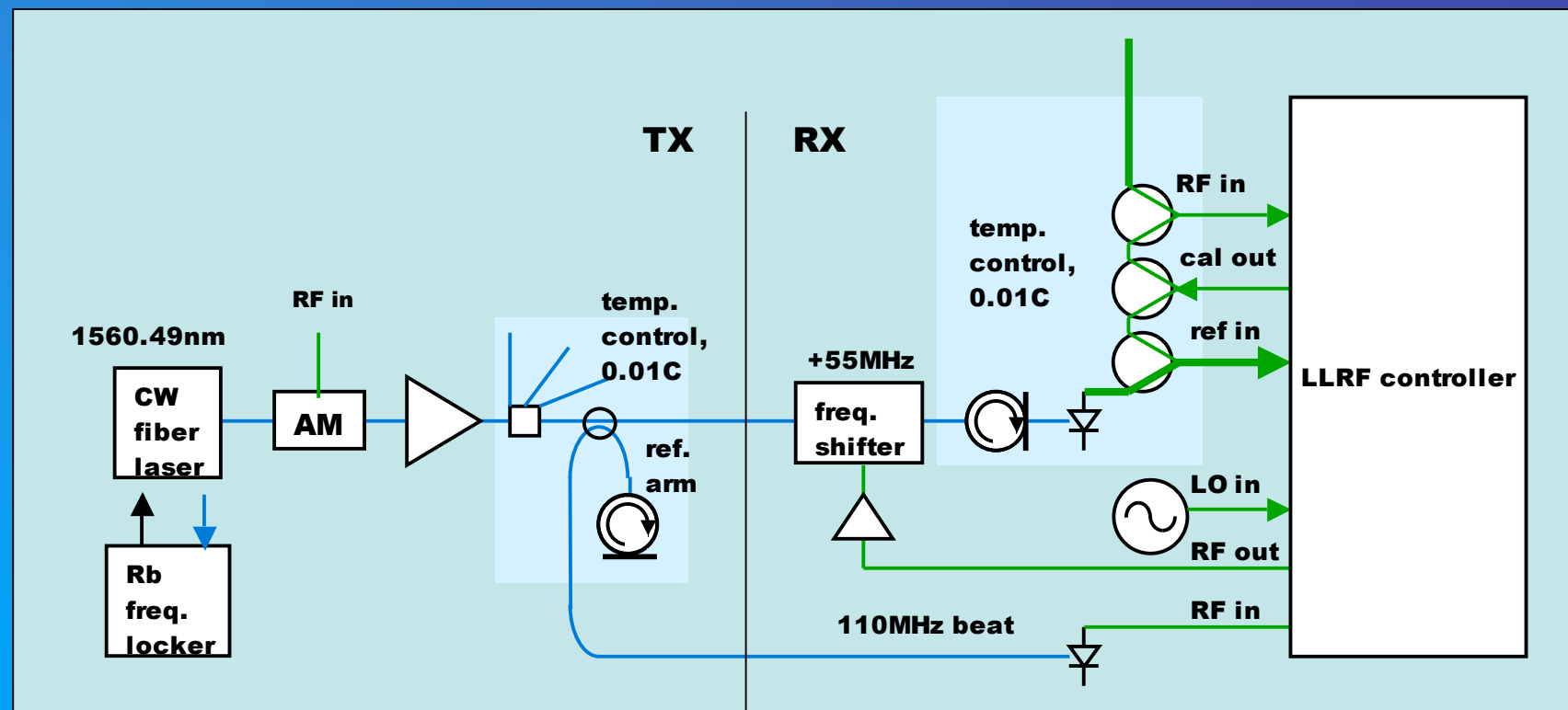


Install. Phase id	items to be delivered & installed	PO ref ID	deliv. date	commiss. with MENLO at ST	
A	- M-Fiber CUSTOM femtosecond Laser	2a	MAY '09	1 week in MAY '09	Timing availability Operational Readiness
	- P250 Pulse EDFA fiber amplifier	2b			
	- SB1-8 Splitter Box	2c			
	- system enclosure	2d			
	- RR electronics	2e			
	- Fast Photodiode	2f			
B	- Balanced Optical μ -wave detector BOM-PD	1f	AUG '09	2 weeks in JUL '09	
C	- Link prototype FLS + LFC	1b 1d	NOV '09	1 week in OCT '09	Included on situ fiber link compensation.
D1	- 3 Links - RR electronics (link)	3) 4)	JAN '10	1 week in DEC '09- JAN '10	Included on situ fiber link compensation.
D2	- 2 Links - RR electronics (link)	3) 4)	APR '10	1 week between APR-MAY '10	Included on situ fiber link compensation.

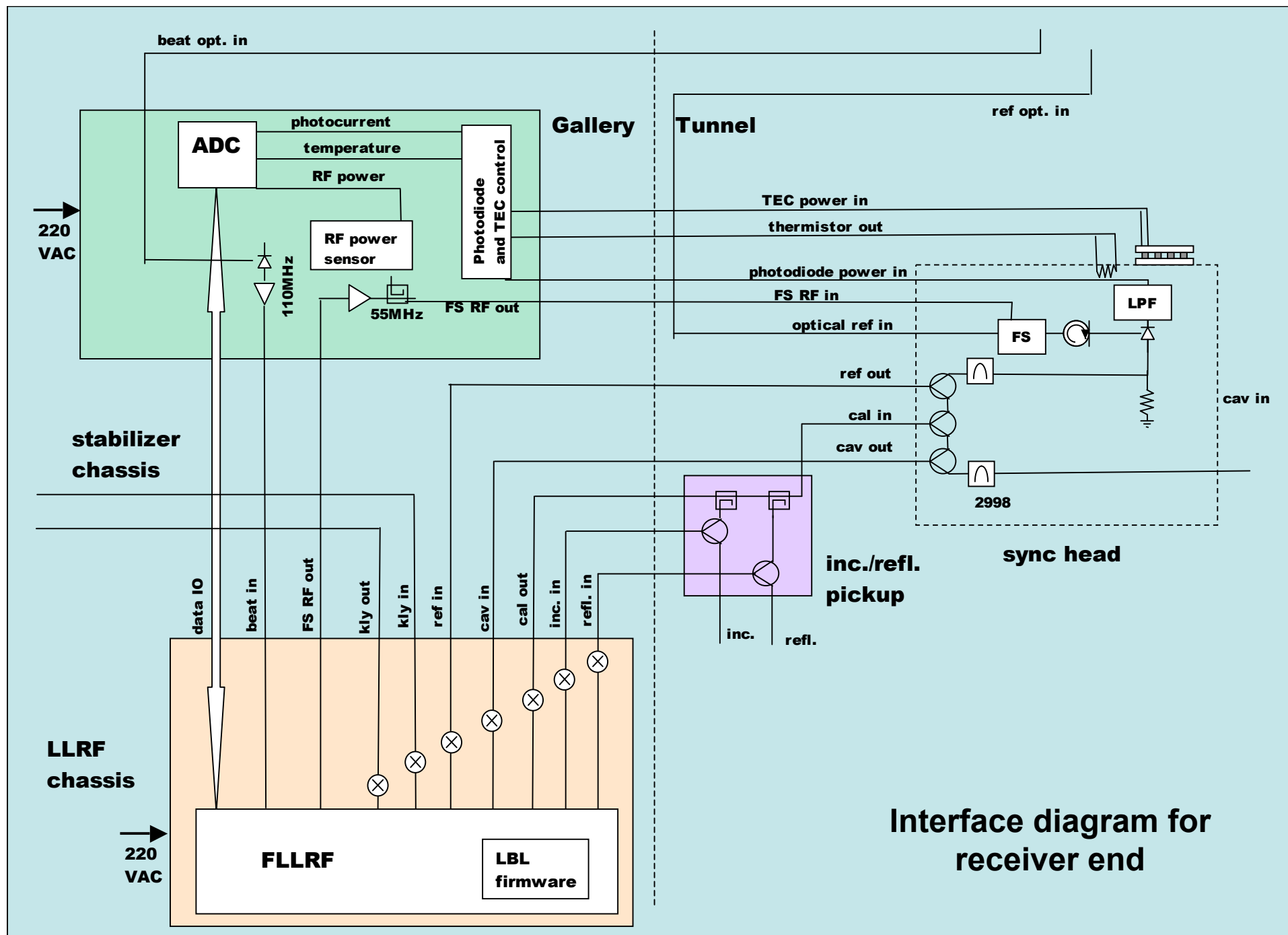


Trieste 03/02/2009
rev. 1.3
written by: M. Ferianis

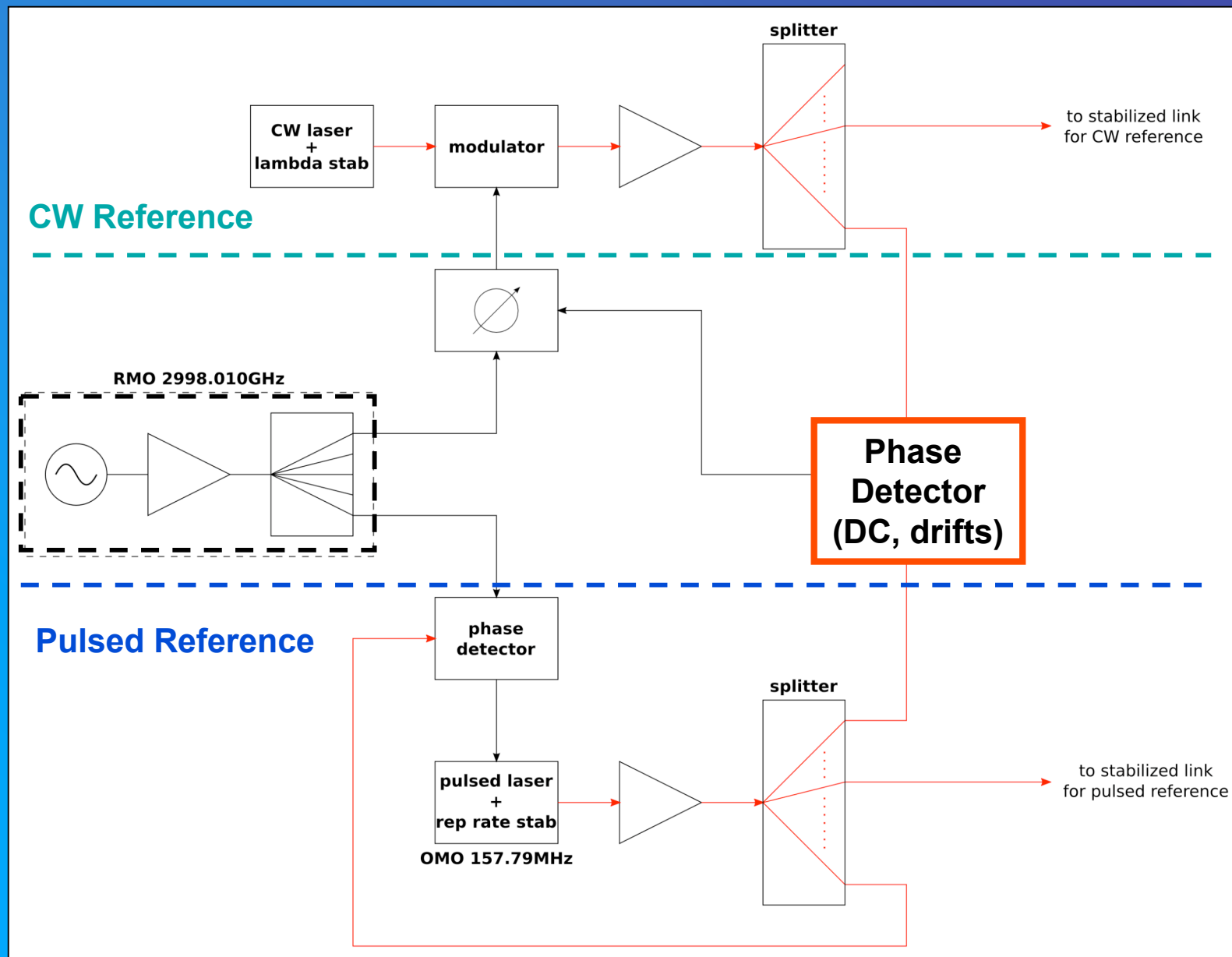
**Installation plan and Acceptance Tests for the
FERMI@elettra Pulsed Timing System**

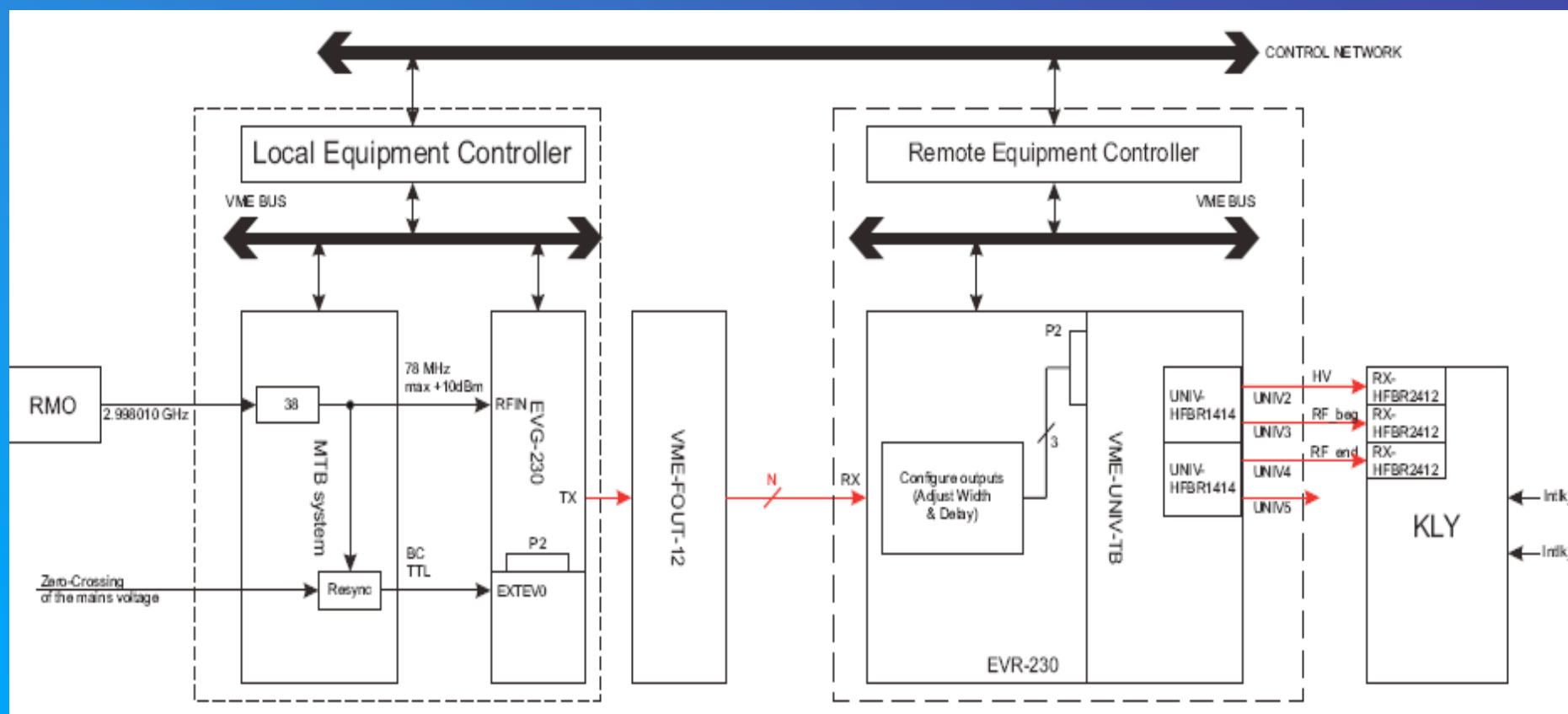


- Changes in line length are sensed by interferometer, signal sent to receiver
- Receiver applies phase shift to frequency shifter RF, stabilizing optical phase at end
- Optical phase correction is used to calculate RF phase shift, including group/phase correction
- Thermal drift of beat fiber delay is $\sim 1\text{ns}$, becomes 0.5fs of optical phase error on main
- Arbitrarily long delay range is possible, limited only by software



Interface diagram for receiver end



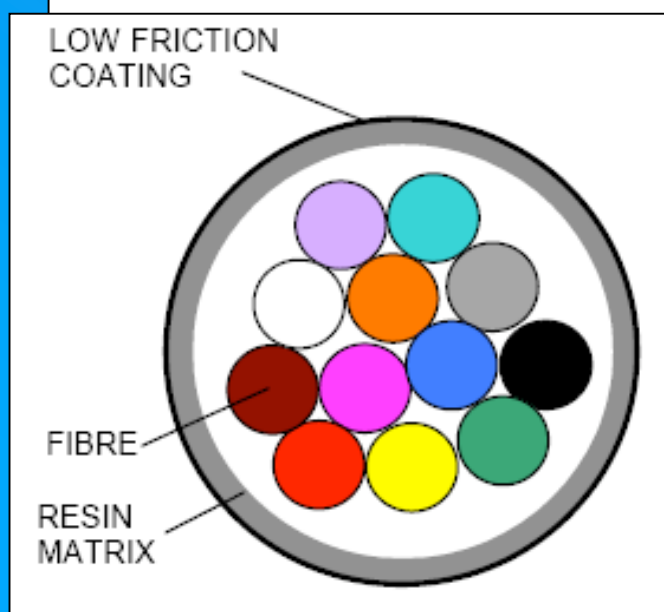


- One EVR in each Equipment Controller of DIAGS, LLRF and Controls
- Measured jitter on remotely generated trigger $< 10\text{ps}_{\text{RMS}}$
- Also during commissioning phase 1 Klystrons will be triggered using the EVRs

CABLAGGIO OTTICO OPTICAL TIMING SYSTEM

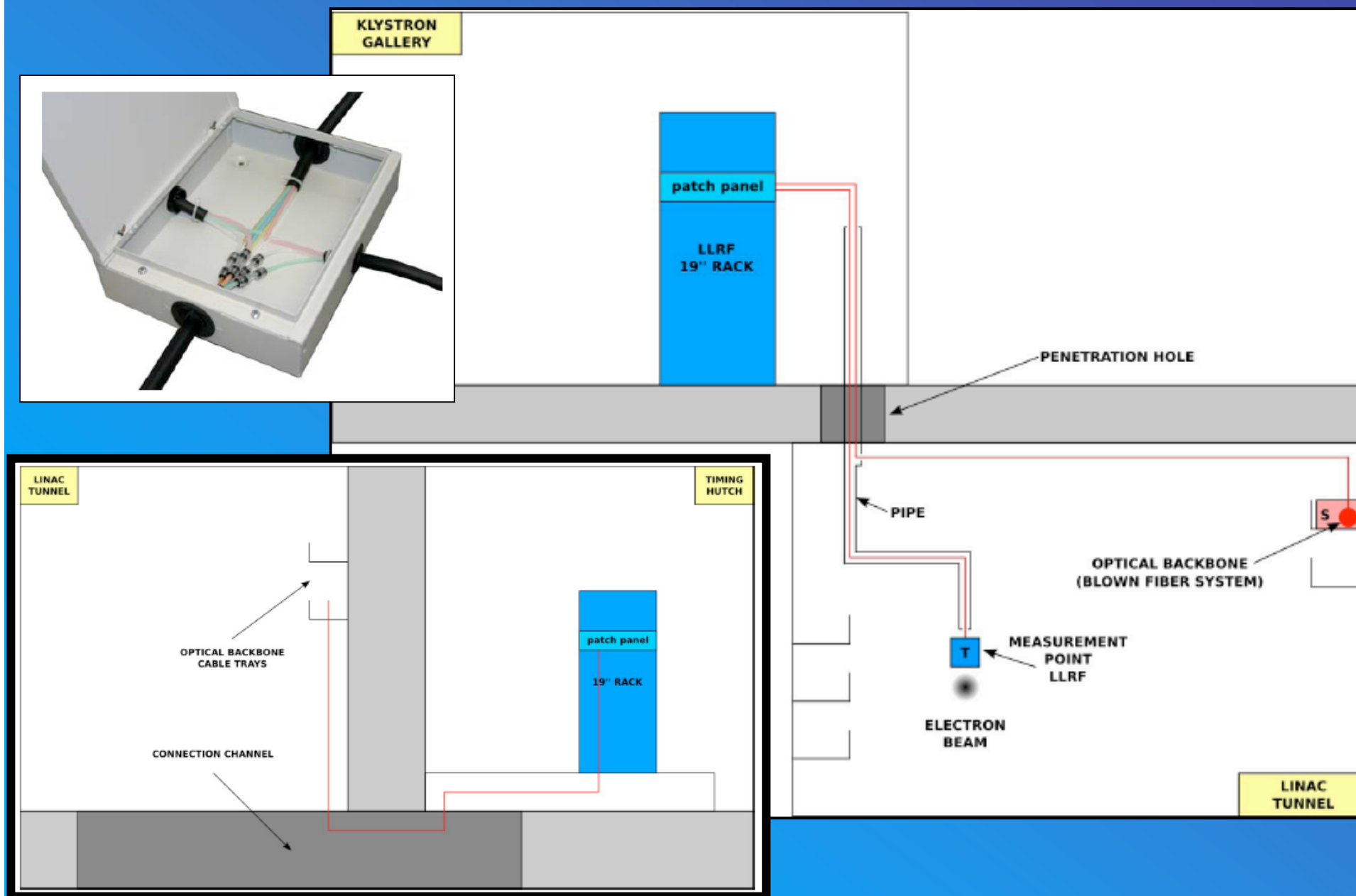
FERMI@elettra

Fabio Rossi



UTENZA	PUNTO DI PARTENZA	PUNTO DI ARRIVO	# SLOT	# FIBRE	NOTE
Impianto LLRF Klystron Spare	Timing Hutch (TH)	Rack LLRF RLLRF_KGSP.01 (RLLRFSP)	2	8 fibre SMF 4 fibre MMF	Attraversamento foro penetrazione HL_KGSP.02
Impianto LLRF Klystron #1	Timing Hutch (TH)	Rack LLRF RLLRF_KG01.01 (RLLRF01)	2	8 fibre SMF 4 fibre MMF	Attraversamento foro penetrazione HL_KG01.03
	Rack LLRF RLLRF_KG01.01 (RLLRF01)	Punto misura RF sezione PHJ nel LINAC Tunnel (MPRF01)	1	4 fibre SMF	
	Rack LLRF RLLRF_KG01.01 (RLLRF01)	Punto misura RF deflettore DF1 nel LINAC Tunnel (MPRF09)	1	4 fibre SMF	Attraversamento foro penetrazione HL_KG01.04
Impianto LLRF Klystron #2	Timing Hutch (TH)	Rack LLRF RLLRF_KG02.01 (RLLRF02)	2	8 fibre SMF 4 fibre MMF	Attraversamento foro penetrazione HL_KG02.01
	Rack LLRF RLLRF_KG02.01 (RLLRF02)	Punto misura RF sezione SOA nel LINAC Tunnel (MPRF02)	1	4 fibre SMF	
	Rack LLRF RLLRF_KG02.01 (RLLRF02)	Punto misura RF sezione SOB nel LINAC Tunnel (MPRF03)	1	4 fibre SMF	Attraversamento foro penetrazione HL_KG02.02

The FERMI@Elettra optical hybrid timing system: Optical Fiber layout



The FERMI@Elettra optical hybrid timing system: Installation Plan



FERMI TIMING INSTALLATION & COMMISSIONING PLAN			resp. res.					MF	15 feb 2009	rev	1,0
ID	milestones		feb-09	mar	apr	may	giu	lug	ago	set	ott
M.1	start of COMM phase 1 (2 S-band ?)										
M.2	COMM phase 1 (+4 S-band ?)										
M.3	end of COMM phase 1										
M.4	shutdown										
M.5	LINAC tunnel (up to BC1): FINITO e PULITO										
M.6	start Installation timing hutch (civil work DONE; no more DUST; still YARD!!!)										
PRE-INSTALLATION TASKS (still YARD)											
T.1	false floor	DB, GM									
T.2	install HVAC & Chiller inside the Timing Hutch; cooling pipes to 2 racks	MM GM									
T.3	cable trays on floor & vs. laser hutch	FDB GM FR									
T.4	install racks; connection to POWER & cooling	FDB GM									
T.5	install Optical Tables (done with ST personnel as usual in EXP HALL)	GM FR									
T.6	posa racks (DIAGS CONTR e LLRF)	GM Lpiv									
INSTALLATION TASKS (YARD ?)											
T.10	DELIVERY of RMO (& TESTING in fs meas laboratory)	MF FR									
T.11	Delivery & Installation of TEMP Monitoring System	MP									
T.12	FO 1st batch (from Timing Hutch to LINAC TUNNEL & KLYSTRON GALLERY)	FR GM									
T.13	PMD measurements from UNI PD	FR+EXT									
T.14	Implementation of FO patch panel in timing hutch	FR GM									
T.15	Impl. of FO patch panels in RACKS in LINAC TUNNEL & KLYSTRON GALLERY	FR GM									

FERMI TIMING INSTALLATION & COMMISSIONING PLAN			resp. res.				MF	15 feb 2009			rev	1,0	
ID	milestones			feb-09	mar	apr	may	giu	lug	ago	set	ott	nov
T.20	Installation of RMO	FR											
T.21	Installation of RB OSC	FR											
T.22	Installation of TIMING EC;	MP											
T.23	Routing of cables / FO to C. ROOM; including Event system FO	GM Lpiv											
T.24	provisional Ref. Signal to PC laser osc. (coax)	FR											
T.25	DELIVERY & INSTALLATION OF OMO & SPLIT BOX	FR MF+EXT											
T.26	Move MIT Table Top stab links (2) HW	FR+EXT											
T.27	Installation of Day (-1) CW RF distribution (2 TX + 6 links)	AB TR											
T.28	Day Zero CW prototype ready (1link)	MF+EXT											
T.29	Mastertime base (10Hz bunch clock)	AB RM											
T.30	Installation of Event_Generator	AB MP											
T.31	Installation of Trigger BC TX units	AB RM											
T.32	Integration into CS of available sub-systems (RMO, OMO, SPLIT, Mastertime base, Ev_Gen etc)												
T.40	CW FINAL Sender ready	FR+EXT											
T.41	development of CW to OMO locking unit, testing in fs lab	FR LB											